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Hahn

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[54] **VARIABLE TRANSFORMER AND VOLTAGE CONTROL SYSTEM**

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[51] **Int. Cl.**³ **G05F 1/14**

[52] **U.S. Cl.** **323/264**; 323/256

[58] **Field of Search** 323/250, 255, 256, 257, 323/259, 260, 264, 331, 344, 347, 348; 336/117, 118, 119, 130, 135

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[57] **ABSTRACT**

A system for automatically controlling output voltage to correct for varying input voltage utilizes a transformer having a movable core structure. The output voltage from the transformer is sensed and made to conform to a predetermined standard by moving the movable core structure, which is then locked in position after its adjustment. Voltage changes are step-free, and linear voltage control with respect to time is achieved through non-linear movement of the core structure over a range of variation of the output voltage.

30 Claims, 5 Drawing Figures

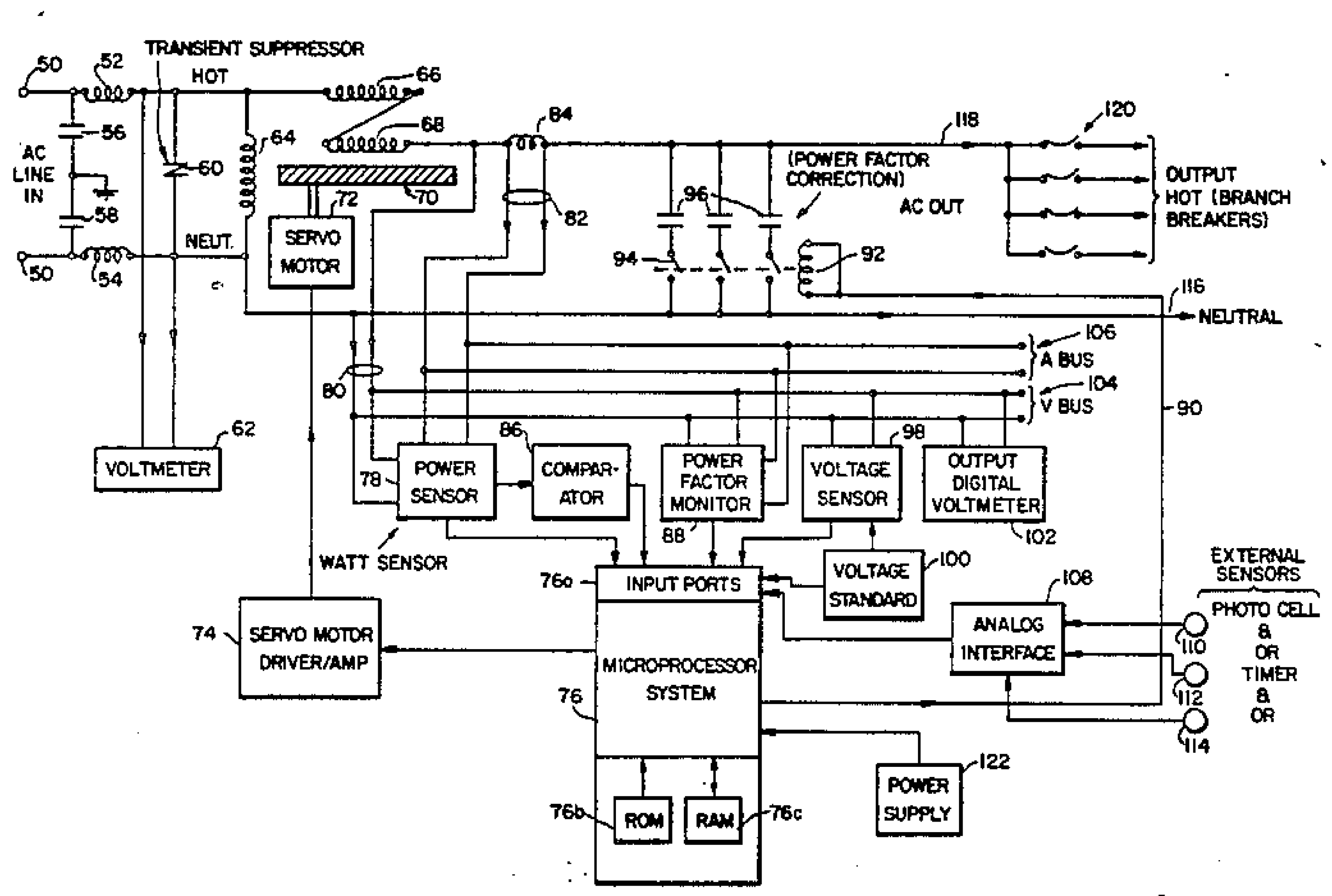


FIG. 3.

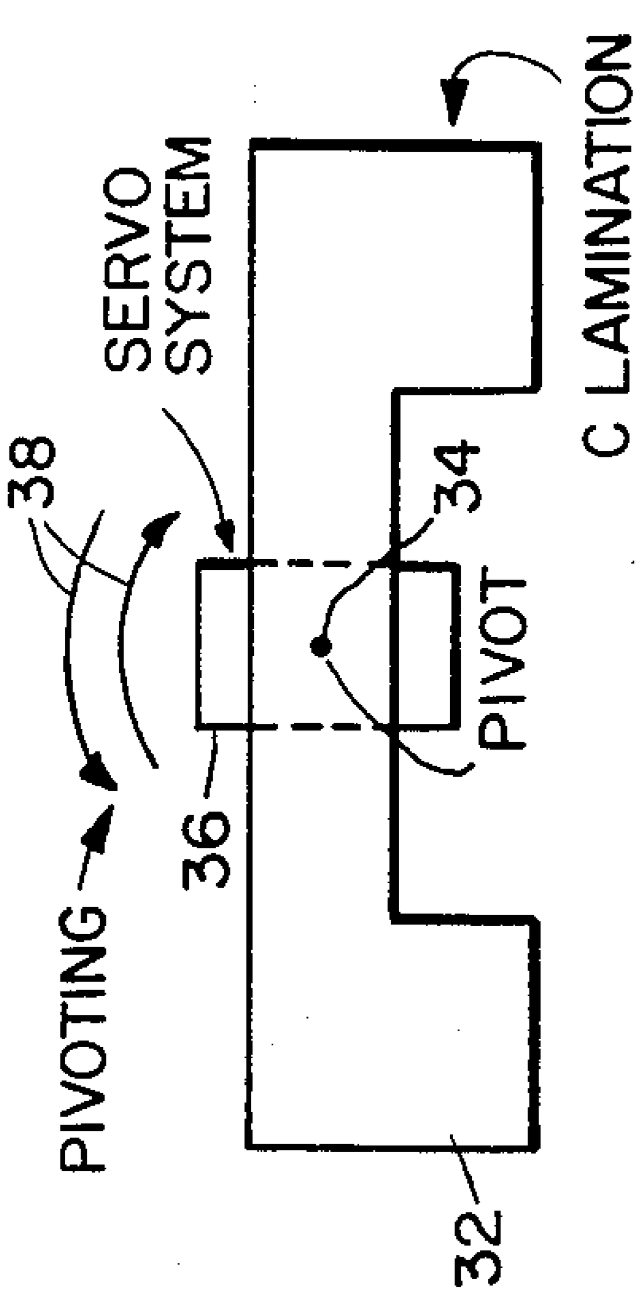


FIG. 4.

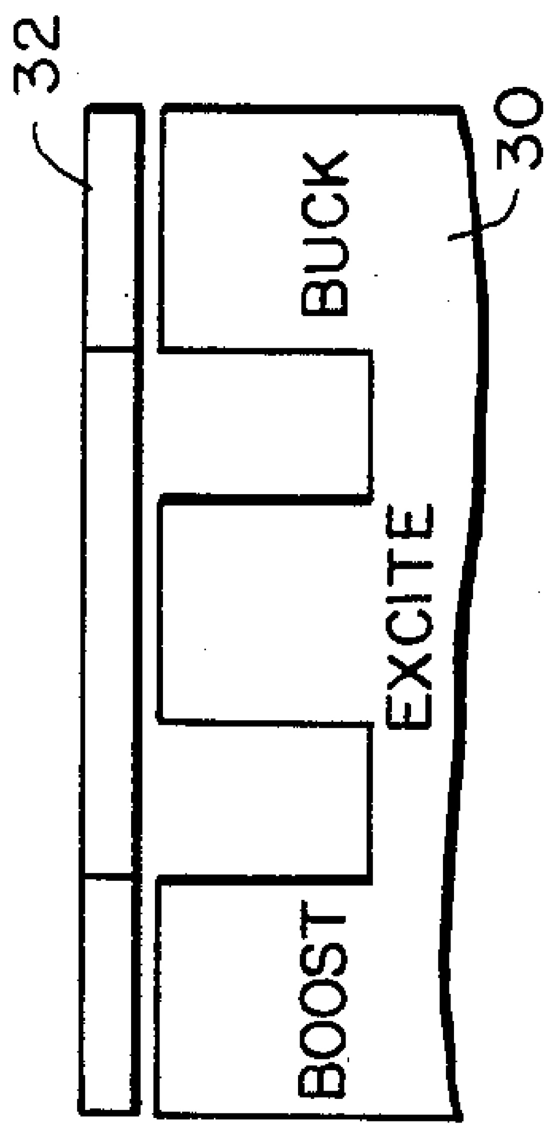


FIG. 5.

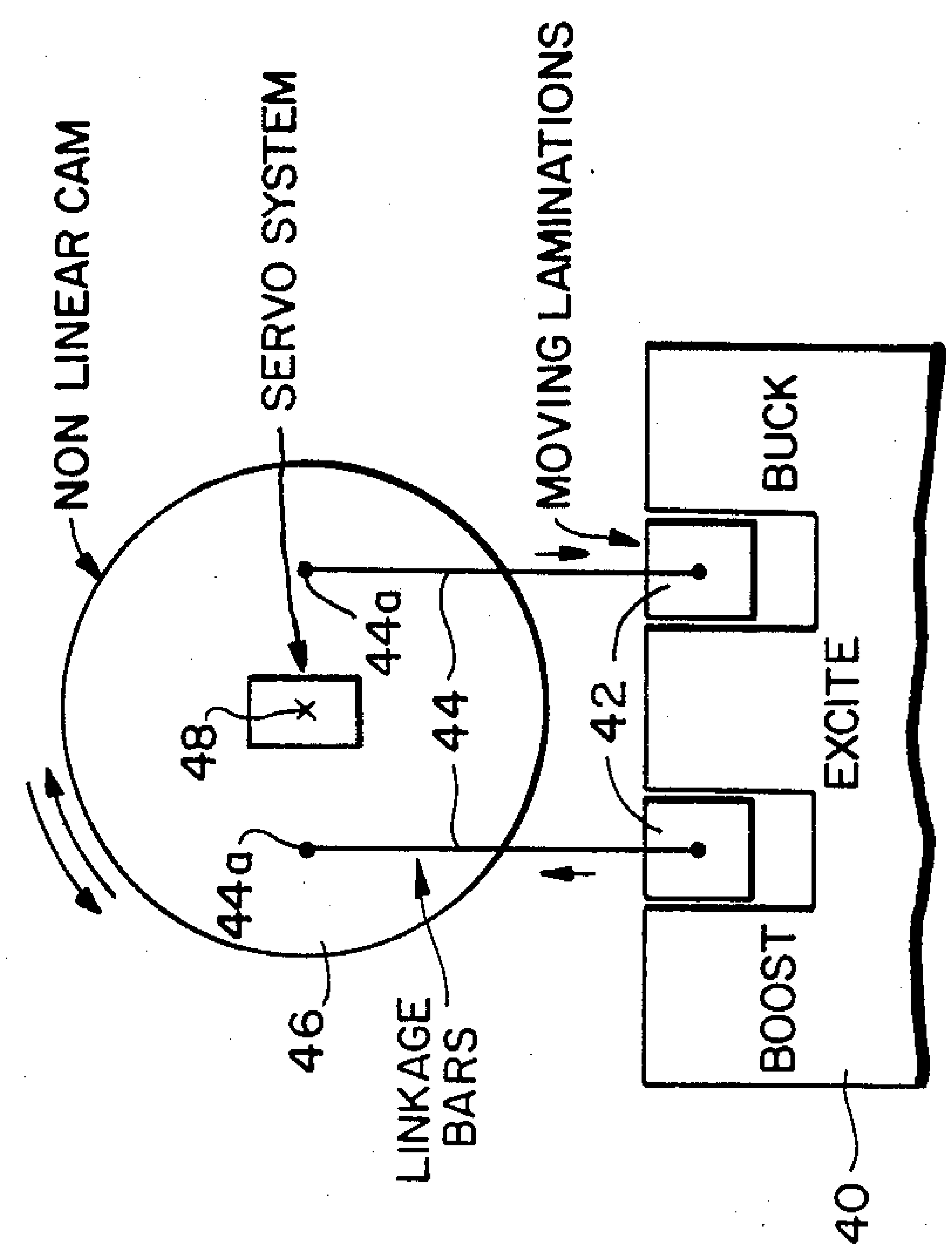


FIG. 1.

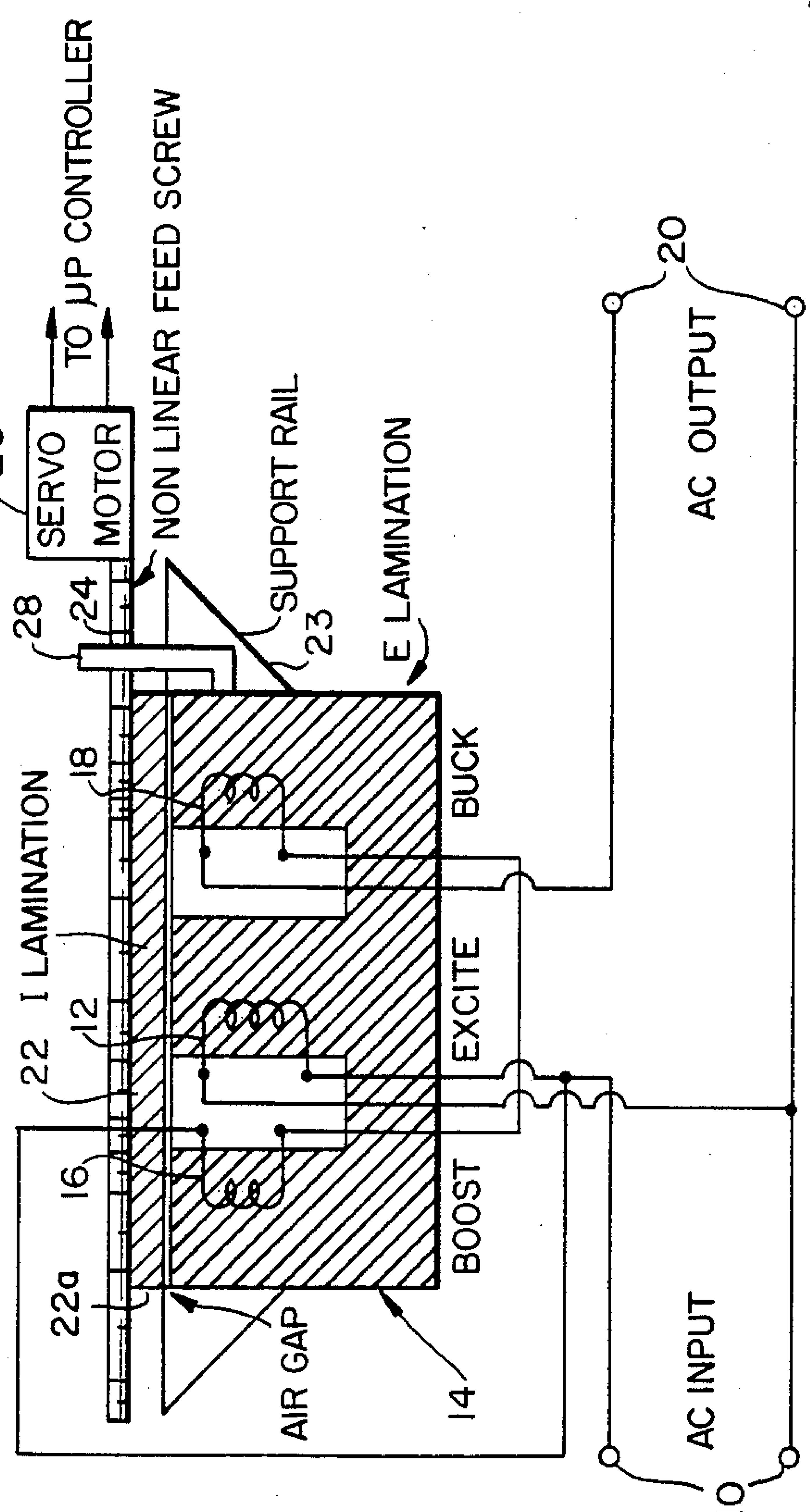
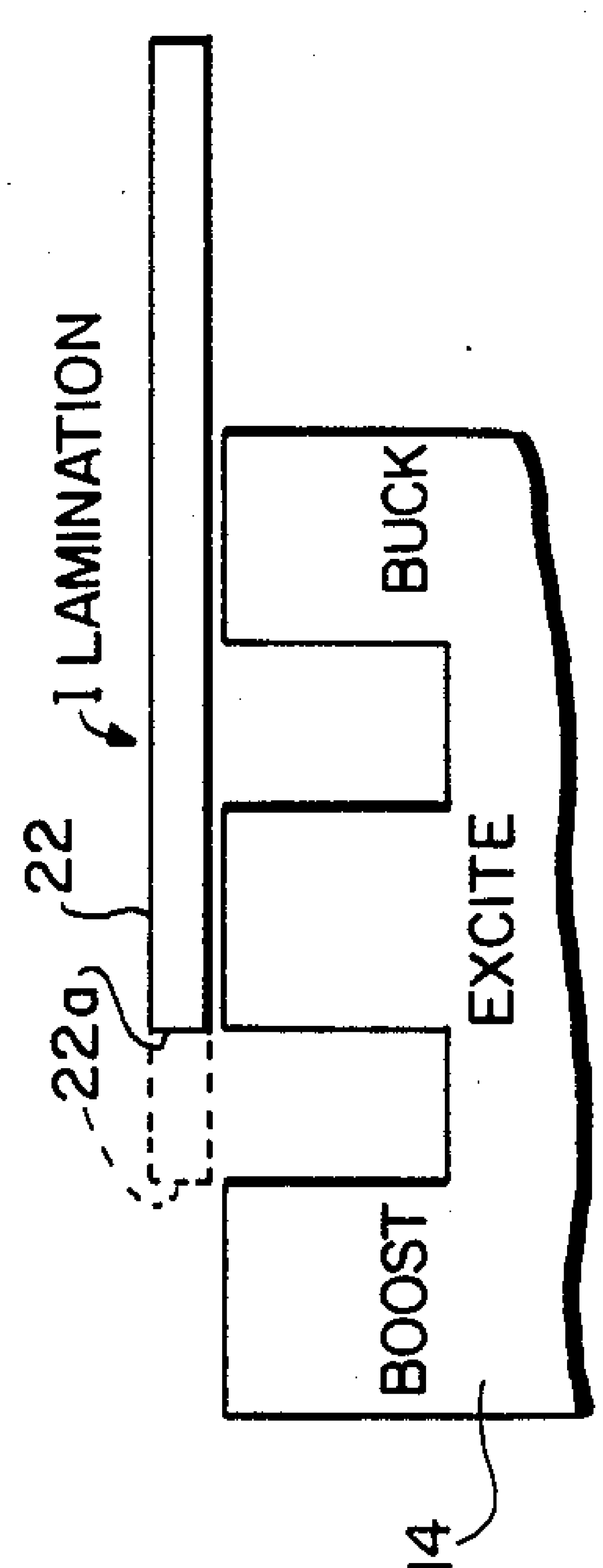
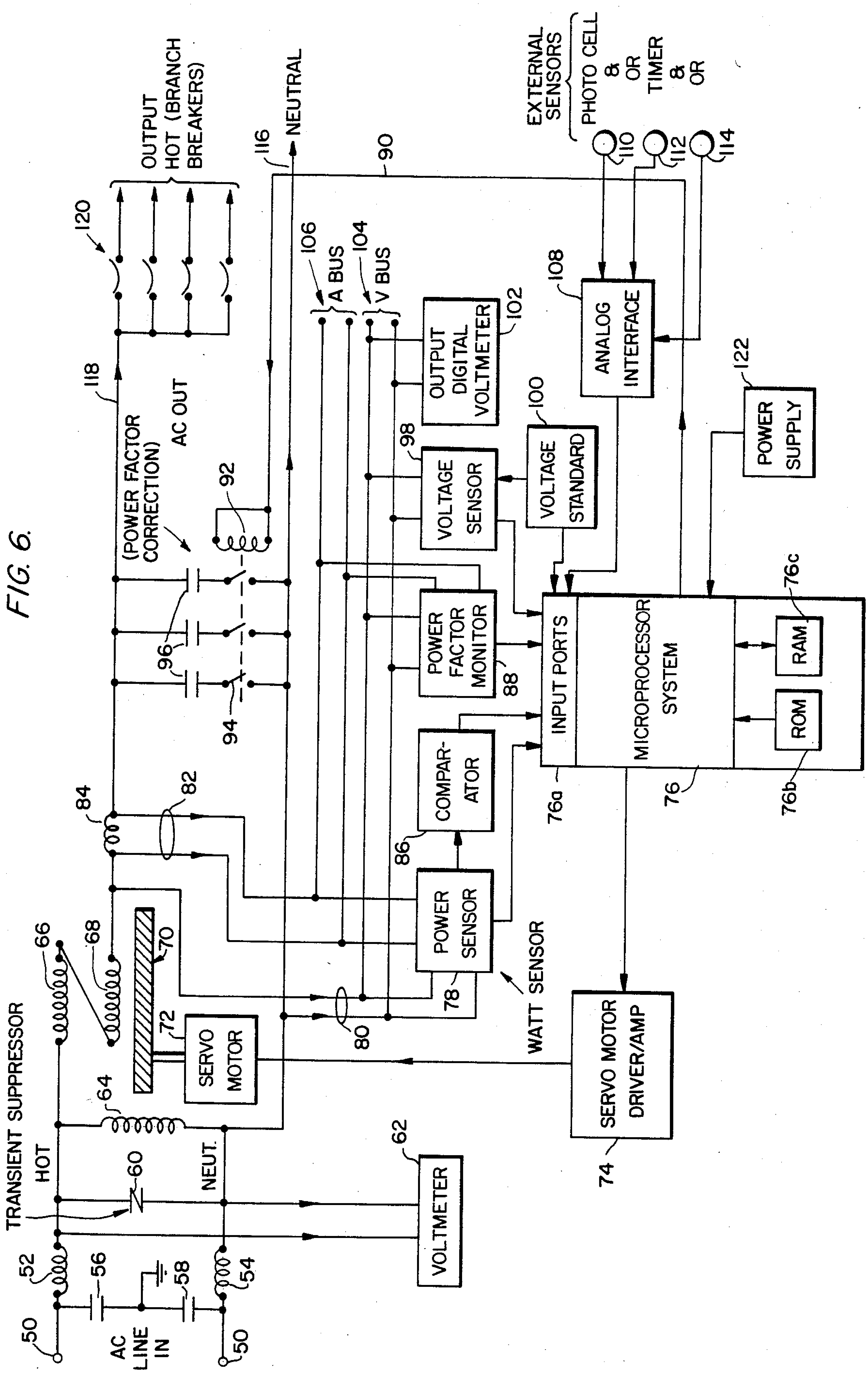


FIG. 2.




OUTPUT HOT (BRANCH BREAKERS)
NEUTRAL
EXTERNAL SENSORS
PHOTO CELL & OR TIMER & OR
A BUS
V BUS
OUTPUT DIGITAL VOLTMETER
ANALOG INTERFACE
POWER SUPPLY
(POWER FACTOR CORRECTION)
AC OUT
VOLTAGE SENSOR
VOLTAGE STANDARD
POWER FACTOR MONITOR
INPUT PORTS
MICROPROCESSOR SYSTEM
RAM
ROM
COMPAR-ATOR
POWER SENSOR
WATT SENSOR
SERVO MOTOR
SERVO MOTOR DRIVER/AMP
TRANSIENT SUPPRESSOR
HOT
NEUT.
VOLTMETER
AC LINE IN
50
52
54
56
58
60
62
64
66
68
70
72
74
76
76a
76b
76c
78
80
82
84
86
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96
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100
102
104
106
108
110
112
114
116
118
120
122
FIG. 6.

VARIABLE TRANSFORMER AND VOLTAGE CONTROL SYSTEM

BACKGROUND AND BRIEF DESCRIPTION OF THE INVENTION

This invention relates to voltage control systems. It has particular application to the control of voltage by a consumer supplied with power from a utility system. The invention is also directed to providing a variable transformer in which a moving core structure is used to achieve step-free voltage control in response to changing input voltages, and in which output voltage is made to change linearly with respect to time.

Power control systems are known. Many involve some form of load shedding, which is undesirable, since it requires removal of one or more devices from use. The present invention is directed to a power control system using voltage control as a principal factor, but also utilizes load shedding or load reduction as desired.

In the past, much publicity has been given to the "brown-out" condition, in which the voltage supplied by a utility to a consumer falls below a desired level. Little attention has been given to the supplying of excessive voltage by a utility. Since a consumer pays for electricity upon the basis of power consumed, i.e., the product of voltage and current and phase angle and since current and power usually increase when voltage increases, excessive power is consumed and paid for by a consumer when voltage increases beyond a desired level. The present invention is directed toward a system for handling conditions of excessive voltage, as well as insufficient voltage, i.e., to supply correct voltage in response to varying input voltage conditions.

The present invention utilizes a variable transformer as a control device. In the past, variable transformers for voltage control purposes have generally involved moving coils or changing/sliding electrical contacts. Both arrangements are undesirable, since electrical conductors are being moved or switched in and out of a circuit, accompanied by arcing, noise, losses, wear, and other problems. The present invention utilizes a transformer structure involving fixed coils, and no moving contacts. Instead, a part of the magnetic core structure is movable, to change the magnetic flux in the transformer that links the windings in the transformer, so as to achieve voltage control. Although movable transformer core structures have been utilized in the past, most have been for manual operation and not for automatic control as in the present invention. Although it has been proposed before to sense voltage and to control the position of a movable core structure in response thereto, the control mechanism has been spring biased or otherwise relatively freely movable, rendering it unsuitable for use in systems involving large currents, in which the magnetic forces generated are such as to cause movement of the movable core structure to a rest position. In the present invention, a movable core structure is locked in position following any adjustment.

Additionally, the present invention utilizes a non-linear movement of the movable core structure, so as to achieve linear changes in voltage over time. In particular, as the movable core structure moves away from a position adjacent to a pole piece, increasing an air gap, the magnetic flux linking these two members would normally sharply decrease, causing an abrupt and sharp voltage change. In the present invention, the movable core structure is made to move relatively slowly when the increasing air gap is encountered, thereby to eliminate this undesirable effect.

The invention will be more completely understood by reference to the following detailed description of presently preferred embodiments thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagrammatic representation of a transformer structure embodying the invention.

FIG. **2** is a simplified view of the structure of FIG. **1**, showing the movable core structure in a position to lower the input voltage by a maximum amount.

FIG. **3** is a simplified top view of another transformer structure embodying the invention.

FIG. **4** is a side view of the transformer structure of FIG. **3**.

FIG. **5** is a simplified view of another transformer structure embodying the invention.

FIG. **6** is a block diagram of an overall system for voltage control embodying the invention.

DETAILED DESCRIPTION

Referring to FIG. **1**, a pair of input terminals **10** receive an AC input from a utility. As an example, this is the AC input to a home, and represents the power supplied by the utility on the home or use side of the meter (not shown) that monitors power delivered to the user. The AC input is applied to a fixed excitation winding **12** that forms part of a transformer **14**. The excitation winding **12** is always energized by the input voltage appearing at the terminals **10**. One of those terminals (the uppermost one in FIG. **1**) is also connected in series with two series-connected transformer secondary windings **16** and **18**. The winding **16** is designated a "boost" winding, while the winding **18** is designated a "buck" winding. The two windings generate potentials which oppose each other, and are thus inserted in series in the "hot" leg of the line. The neutral line in the system is the lowermost electrical conductor in FIG. **1**. Thus the AC output appears across terminals **20**.

The transformer in FIG. **1**, which is a presently preferred embodiment, is a conventional, E-type transformer structure. The conventional fixed I lamination is not included within the E lamination stack. Instead, the I lamination in FIG. **1**, designated **22**, bridges the entire E lamination structure and is movable. In particular, it is carried by a support rail system **23**, riding immediately above the E laminations. The spacing between the I and E laminations is normally in the order of a few thousandths of an inch. The position of the movable core structure **22** is controlled by a feed screw **24**. Preferably, the feed screw is non-linear, e.g., by having a varying thread pitch. This non-linearity is the reason for a linear voltage control, as will be explained in more detail below. The feed screw **24** is under the control of a servo motor **26** which is in turn controlled by a microprocessor system, such as is shown in FIG. **6** to be explained in detail below.

In the relative positions of the movable core structure **22** and the fixed E core structure in FIG. **1**, both the boost winding **16** and the buck winding **18** develop the same potentials, which cancel each other, and hence the AC input voltage at the terminals **10** appears as the AC output voltage at the terminals **20** (except for very small losses within the transformer system itself). Assume that the servo motor **26** moves the movable core structure **22** to the position shown in FIG. **2**. In this position the boost winding **16** of FIG. **1** is essentially ineffective, since the movable core structure **22** does not provide a completed flux path for that winding. The flux path for the buck winding **18**, on the other hand, is totally completed, and hence the buck winding develops its maximum potential which is subtracted from the input potential appearing at the input terminals **10**. The AC output potential appearing across the terminals **20** is thus reduced by the maximum amount.

Conversely, if the movable core structure **22** is moved by the servo motor **26** of FIG. **1** to its other extreme position, in which the buck winding **18** is essentially isolated, the maximum addition in input voltage is provided by the boost coil **16**, resulting in a maximum raising of the AC output potential in the terminals **20** over the input potential at the terminals **10**.

Variable voltage control at the AC output terminals **20** may be achieved by suitable energization of the servo motor **26** and movement of the movable core structure **22**. At any time that the servo motor **26** is not operating, and the core structure **22** is not moving, that core structure is effectively locked in position and cannot be moved. Thus even if forces are developed within the transformer core structures tending to move the movable core piece **22** to a position which maximizes flux linkage between the core pieces, no movement of the core structure **22** can result except as occasioned by the servo motor **26**.

Because of the feed screw **24**, movement of the core piece **22** is continuous, and there need be no abrupt step-like changes in output voltage at the terminals **20**. Smooth variation of output potential is also achieved by utilizing a non-linear feed screw. As indicated above, the pitch of the feed screw is made to vary. In particular, the pitch is the greatest (the threads are most widely spaced apart) in that portion of the feed screw **24** that engages threaded support **28** when the moving core piece **22** is in the position such as shown in FIG. **1**. However, assume a condition in which forward end **22*a*** of the movable core structure **22** is moving from adjacent the fixed pole piece that carries the boost winding **16** (as shown in dashed line in FIG. **2**). During this time when the movable core piece is virtually leaving the pole piece, the flux linking the pole pieces is undergoing a rapid change, and at this time the threads of the feed screw **24** pull the movable pole piece **22** very slowly (the threads are most closely spaced). In this fashion, a feed screw of non-linear pitch produces a linear voltage change with respect to time.

In other words, the movable core structure **22** is moved at a rate which decreases as the gap between that core element and one of the boost and buck coils increases. The thread pitch varies so that it is greater when end **22*a***, for example, of the movable core piece **22** is positioned between adjacent ones of the fixed E pole pieces than when the end **22*a*** is positioned over one of those pole pieces.

An alternative transformer structure is shown in FIGS. **3** and **4**. A fixed core structure **30** of E type as in FIG. **1** may be employed, together with a C-type lamination or movable core piece **32**. The movable core piece **32** is pivoted about a pivot axis **34** by any suitable servo motor **36**. Pivoting is as shown by arrows **38** in FIG. **3**. A non-linear feed screw such as the feed screw **24** may be employed in the system of FIG. **3** to achieve the smooth voltage control as in the system of FIG. **1**.

In both systems of FIGS. **1** and **3** and **4**, linear mechanical drive mechanisms may be employed, if desired, in conjunction with a variable speed servo motor or non-linear movement under the control of a microprocessor, as in the system of FIG. **6** to be described below.

FIG. **5** illustrates another transformer system involving an E-type fixed core structure **40**. In this case, movable core pieces **42** are employed that move in the gaps between the fixed pole pieces, each moving along a line of movement. The movable pole pieces **42** are driven by linkage bars **44** which are pivotally coupled each at one end thereof (as at **44*a***) to a drive member **46** that is pivotable about a pivot axis **48**. The other ends of the linkage bars **44** are pivotally coupled to the movable core pieces **42**. Arcuate movement of the end of the linkage bar **44** coupled to the drive member **46** (about the pivot axis **48**) causes movement of the movable core piece. That movement is greatest in the position of the drive member **46** shown in FIG. **5**. When the drive member **46** is pivoted to a position in which one of the movable core pieces **42** is leaving the region between the fixed core pieces (i.e., the air gap is increasing), the movement of that core piece is slowed, thereby causing a linear voltage change to take place over time rather than non-linear.

FIG. **6** shows an overall system incorporating one of the transformer mechanisms described above, and also utilizing microprocessor control. The AC line input appears at terminals **50**. A noise suppression filter formed from coils **52** and **54** and capacitors **56** and **58** is included. A transient suppressor **60** between the lines may also be utilized, e.g., a V Mos type device. Input voltage is monitored by the volt meter **62**.

A variable transformer, of the type described above, is utilized involving excitation winding **64** and boost winding **66**, and buck winding **68**, in conjunction with movable core structure **70**, all under the control of a servo motor **72**. That servo motor is under the control of a driver/amplifier unit **74** which, in turn, is controlled by a microprocessor system **76**.

A power or watt sensor **78** is utilized, receiving voltage input signals from the transformer output via conductors **80** and a signal on conductors **82** representing current flow in the system. The conductors **82** are connected to a current transformer **84**. The power sensor **78** develops an output signal which is applied to the microprocessor system **76** via input ports **76*a*** of that system. A comparator **86** may be included, as desired, settable by the user to a peak demand setting (in watts) desired by the user. This comparator is thus applied by a signal from the power sensor **78**. If the peak demand is sensed by the comparator **86**, a suitable output signal is developed, applied to the microprocessor system, causing that system to control the servo motor driver/amplifier **74** to reduce the output voltage, and causing a concomitant reduction in consumed power.

A power factor monitor **88** may be employed, as desired, receiving input signals from the current transformer **84** representing current flowing in the system, as well as voltage signals from the conductors **80** representing voltage in the system. The power factor monitor **88** thus develops a signal applied to the microprocessor system **76** which may be used for the correction of power factor, as desired. In particular, the microprocessor system **76** may develop a signal upon conductor **90** (a bus conductor) which energizes relay **92** to cause switches **94** to be closed, thereby switching across the AC output lines of the system power factor correction capacitors **96**. It should be noted that inductive loading is the most commonly encountered cause of power factor deterioration. Thus, capacitive correction has been shown as a feature in the system of FIG. 6. Obviously, inductive correction could be employed in a system involving heavy capacitive loading.

In the system of FIG. 6, the AC output potential of the transformer system, as monitored via the conductors **80**, is used for voltage sensing by a voltage sensor **98**. That sensed voltage is supplied to the microprocessor system **76**. A voltage standard may be set by the user in unit **100**, so that the microprocessor system **76** may compare the actual voltage as sensed by the sensor **98** with that desired (as indicated by the standard **100**). Suitable control signals are thus developed by the microprocessor system, controlling the servo motor driver/amplifier **74** to change in turn the output voltage of the system through the variable transformer described above.

An output indicator **102** may be employed to provide a visual indication of the voltage output in the system, e.g., an output digital volt meter. In this regard, it should be noted that a voltage output "bus" **104** is provided, as well as a current output indication bus **106** for the purpose of further monitoring of output voltage and amperage, as desired. The bus **104** is taken from the conductors **80**, while the bus **106** is taken from the current transformer **84**.

An interface **108** may be included to couple various external sensors such as photo cell **110**, timer **112**, or other external sensing device **114** to the microprocessor system **76**. All of these external sensors may be utilized to provide control of the voltage in the system in accordance with various external criteria, such as time of day, ambient light conditions, temperature, to name some examples. For example, if the system of FIG. **6** is used principally with regard to a lighting load, it may be desired to reduce the output voltage and concomitantly the generated light output in the event that ambient light increases over a certain level, or nighttime conditions prevail (when it is desired to achieve a minimal, dim lighting level). Many factors may be monitored and used for voltage control purposes.

To complete the description of the system of FIG. **6**, the output voltage from the variable transformer system appears across neutral conductor **116** and "hot" conductor **118**. Multiple circuit breakers **120** may be employed to provide branch circuits. For load shedding purposes, any one or more of these circuit breakers may be under the control of the microprocessor system **76**, to open the breakers and to shed loads, as desired, in the event that power consumption remains excessive notwithstanding other corrective measures being taken by the system of FIG. **6**.

A power supply **122** conventionally supplies the microprocessor system and other of the devices with power, as necessary, for functioning.

The microprocessor system **76** is conventional and may comprise conventional analog-digital convertors and a microprocessor such as a Motorola 6500 series, an Intel 8080 model, and other suitable microprocessor units. The microprocessor system **76** includes read only memory (ROM) **76*b*** and random access memory(RAM) **76*c***. The operating instructions for the system would reside in the ROM **76*b***, while the data representing monitored conditions and desired conditions, as developed by the various monitors and sensors described above, reside in the memory **76*c***.

The invention described above has been explained in terms of presently preferred embodiments thereof. In particular, a single phase system has been shown. Obviously, the invention is applicable to multi phase systems. These and other changes and modifications will be readily apparent to those skilled in the art. Accordingly, the invention should be taken to be defined by the following claims.

What is claimed is:

1. A system for automatically controlling output voltage in a system supplied with a varying input voltage comprising a transformer supplied with said input voltage and producing said output voltage and having coils and a movable core structure, the position of said core structure determining the relation between said input and output voltages, said movable core structure including means for locking the position of said movable core structure in any position within a predetermined range, and control means responsive to variation in said output voltage for varying the position of said movable core structure to maintain said output voltage at a predetermined value, in which said control means moves said movable core structure nonlinearly over a range of variation of said output voltage.

2. A system according to claim **1**, in which said transformer includes a boost coil for adding voltage and a buck coil for subtracting voltage, and said movable core structure varies the potential developed by each of said boost and buck coils.

3. A system according to claim **2**, in which said movable core structure includes a core element movable in proximity to said boost and buck coils.

4. A system according to claim **3**, in which said movable core structure is moved at a rate which decreases as the gap between said core element and one of said boost and buck coils increases.

5. A system according to claim **3**, in which said transformer includes a fixed core structure having fixed pole faces in a first plane, and said movable core structure comprises a member having at least one pole face movable in a plane parallel to said first plane.

6. A system according to claim **5**, in which said movable pole face moves along a line, said control means comprises a feed screw coupled to said movable pole face to move the latter.

7. A system according to claim **6**, in which said feed screw includes a thread pitch that varies.

8. A system according to claim **7**, in which said thread pitch varies at a control position so that the pitch is greater when an end of said movable pole face is positioned between adjacent ones of said fixed pole faces than when said end is over one of said fixed pole faces.

9. A system according to claim **5**, in which said movable core structure has two pole faces and is pivotable so that one face thereof is adjacent one fixed pole face when the other face thereof is remote from another fixed pole face.

10. A system according to claim **3**, in which said core element is movable along a line, and said control means comprises a drive member pivotable about a pivot axis, a linkage bar pivotally coupled at one end thereof to said drive member at a point spaced from said pivot axis and at another end thereof to said core element, so that arcuate movement of said one bar end about said pivot axis causes movement of said core element along said line.

11. A system according to claim 10, in which there are two of such core elements movable along lines parallel to each other, and two of such linkage bars coupled to points on said drive member on opposite sides of said pivot axis.

12. A system according to claim 1, in which said control means includes microprocessor means monitoring said output voltage and generating output control signals, and servo motor means coupled to said movable core structure to control the position of the latter in response to said output control signal.

13. A system according to claim 12, in which said microprocessor means monitors electrical current output from said transformer, and including reactive impedance means under control of said microprocessor means and selectively connectable to the output of said transformer to provide for automatic adjustment of the relation between output voltage and current from said transformer.

14. A system according to claim 12, including means for monitoring one or more external conditions and generating one or more sensing signals representing the same which are applied to said microprocessor means to vary the position of said movable core structure in accordance therewith.

15. A system according to claim 12, in which said microprocessor means controls said servo motor means to move said movable core structure at a rate that varies in accordance with the position of said movable core structure with respect to said coils.

16. A system according to claim 15, in which said microprocessor means causes said core speed to decrease as the magnetic flux linkage between said coils and said movable core structure decreases.

17. In a variable transformer having a movable core piece that moves past a pole face, the improvement comprising a controller for controlling the movement of said core piece so that said core piece moves at varying rates depending upon the position of said core piece with respect to said pole face.

18. A variable transformer according to claim 17, in which said controller controls said core piece to move at a rate which decreases as the magnetic flux linkage between said core piece and pole face decreases.

19. A variable transformer according to claim 17, in which said controller comprises a feed screw coupled to said movable core piece, said feed screw having a thread pitch that varies.

20. A variable transformer according to claim 19, in which said thread pitch varies so that it decreases at a control position as the magnetic flux linkage between said core piece and pole face decreases.

21. A variable transformer according to claim 17, including a generally C-shaped fixed core piece and a generally C-shaped movable core piece superimposed with respect thereto, and said controller comprises a pivotal mounting of said movable core piece with respect to said fixed core piece.

22. A variable transformer according to claim 17, in which said movable core piece is movable along a line, and said controller comprises a drive member pivotable about a pivot axis, a linkage bar pivotally coupled at one end thereof to said drive member at a point spaced from said pivot axis and at another end thereof to said movable core piece, so that arcuate movement of said one bar end about said pivot axis causes movement of said movable core piece along said line.

23. A variable transformer according to claim 17, in which said controller comprises a microprocessor generating a control signal for controlling the movement of said core piece in accordance with a monitored condition.

24. A system for automatically controlling output voltage in a system supplied with a varying input voltage comprising a transformer supplied with said input voltage and producing said output voltage and having coils and a movable core structure, the position of said core structure determining the relation between said input and output voltages, said movable core structure including means for locking the position of said movable core structure in any position within a predetermined range, and control means responsive to variation in said output voltage for varying the position of said movable core structure to maintain said output voltage at a predetermined value, in which said transformer includes a boost coil for adding voltage and a buck coil for subtracting voltage, and said movable core structure varies the potential developed by each of said boost and buck coils, said movable core structure includes a core element movable in proximity to said boost and buck coils, and said movable core structure is moved at a rate which decreases as the gap between said core element and one of said boost and buck coils increases.

25. A system for automatically controlling output voltage in a system supplied with a varying input voltage comprising a transformer supplied with said input voltage and producing said output voltage and having coils and a movable core structure, the position of said core structure determining the relation between said input and output voltages, said movable core structure including means for locking the position of said movable core structure in any position within a predetermined range, and control means responsive to variation in said output voltage for varying the position of said movable core structure to maintain said output voltage at a predetermined value, in which said transformer includes a boost coil for adding voltage and a buck coil for subtracting voltage, and said movable core structure varies the potential developed by each of said boost and buck coils, said movable core structure includes a core element movable in proximity to said boost and buck coils, said transformer includes a fixed core structure having fixed pole faces in a first plane, and said movable core structure comprises a member having at least one pole face movable in a plane parallel to said first plane, said movable pole face moves along a line, said control means comprises a food screw coupled to said movable pole face to move the latter, and said feed screw includes a thread pitch that varies.

26. A system according to claim 25, in which said thread pitch varies at a control position so that the pitch is greater when an end of said movable pole face is positioned between adjacent ones of said fixed pole faces than when said end is over one of said fixed pole faces.

27. A system for automatically controlling output voltage in a system supplied with a varying input voltage comprising a transformer supplied with said input voltage and producing said output voltage and having coils and a movable core structure, the position of said core structure determining the relation between said input and output voltages, said movable core structure including means for locking the position of said movable core structure in any position within a predetermined range, and control means responsive to variation

in said output voltage for varying the position of said movable core structure to maintain said output voltage at a predetermined value, in which said control means includes microprocessor means monitoring said output voltage and generating output control signals, and servo motor means coupled to said movable core structure to control the position of the latter in response to said output control signal, and said microprocessor means controls said servo motor means to move said movable core structure at a rate that varies in accordance with the position of said movable core structure with respect to said coils.

28. A system according to claim **27**, in which said microprocessor means causes said core speed to decrease as the magnetic flux linkage between said coils and said movable core structure decreases.

29. A system for automatically controlling output voltage in a system supplied with a varying input voltage comprising a transformer supplied with said input voltage and producing said output voltage and having coils and a movable core structure, the position of said core structure determining the relation between said input and output voltages, said movable core structure including means for locking the position of said movable core structure in any position within a predetermined range, and control means responsive to variation in said output voltage for varying the position of said movable core structure to maintain said output voltage at a predetermined value, in which said transformer includes a boost coil for adding voltage and a buck coil for subtracting voltage, and said movable core structure varies the potential developed by each of said boost and buck coils, said movable core structure includes a core element movable in proximity to said boost and buck coils, and said core element is movable along a line, and said control means comprises a drive member pivotable about a pivot axis, a linkage bar pivotally coupled at one end thereof to said drive member at a point spaced from said pivot axis and at another end thereof to said core element, so that arcuate movement of said one bar end about said pivot axis causes movement of said core element along said line.

30. A system according to claim **29**, in which there are two of such core elements movable along lines parallel to each other, and two of such linkage bars coupled to points on said drive member on opposite sides of said pivot axis.

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